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AN ANALYSIS OF FORCE-TIME CHARACTERISTICS OF SELECTED SPRINT STARTS IN SWIMMING

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "An Analysis of Force-Time Characteristics of Selected Sprint Starts in Swimming," submitted by E. Neil Russell in partial fulfilment of the requirements for the degree of Master of Arts.

DEDICATION

To my parents, whose untiring faith, guidance, and confidence has made all this possible.

ABSTRACT

The purpose of the study was to analyze the different component forces, and their length and time of application, from the first recorde application of force until the swimmer cleared the block, for starts involving three different arm movements. Sub-problems investigated were the effect of the arm movements on the movement time of the sprint starter, and the relationship between impulses calculated from the force graphs and impulses determined cinematographically.

Four experienced male competitive swimmers participated as subjects and were individually trained for six hours over a five week period, on three types of sprint starts. The starts were the full arm circle, the partial arm circle, and the arms back. A constant preferred foot spacing was used. Following the training period the subjects were tested on a starting block mounted on a force platform, completing three trials for each of the three types of starts, under normal competitive swimming conditions and rules. Each trial was simultaneously photographed for cinematographical analysis.

It was concluded that no significant differences occurred between movement times or velocities for the three types of starts. A knowledge of the movement time did not enable the prediction of starting velocity for any of the three types of starts. Correlation of impulses determined from the force platform readout graphs and impulses determined by cinematographical techniques indicated that the force platform was a valid instrument of measurement.

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CHAPTER I

STATEMENT OF THE PROBLEM

I. INTRODUCTION

There has been very little reported research dealing with sprint starts in swimming. This is possibly due to the difficulties associated with working beside or over water, and the lack of suitable equipment to measure forces. Heusner (28) has studied the take-off angle of the sprint swimmer. Experimentation in the early World War II period (33, 44, 45, 46) dealt with the holding time, respiration, and the effect that the use of a starting block had on the sprint swimmer's starting time (the period from the stimulus until the sprinter left his mark). The value that these studies have to present day coaches and competitors appears to be small.

Armbruster, Allen, and Harlan (1:55) stated that:

> The competitors with the fastest starting times have a significant advantage over those who are slow in leaving the marks. Likewise a fast swimmer may see his efforts go for naught if for some reason he fails to leave his mark with precise, forceful, and well-timed movements.

Henry (25:302) in studying the sprint start in track stated that:

> A forceful start must necessarily, on straight forward physical grounds, impart a greater velocity to the runner's body mass. Even though the greater velocity is secured at the expense of an initial time loss, it should result in a faster run

> although the sprinter with the quicker but weaker start may lead for a few yards.

In this same study Henry mentioned that vertical force has no effect on the sprint start in track. However, other research pertaining to this parameter in the sprint start in track or swimming is not available. Thus it can only be concluded that the amount of vertical force, and its possible contribution to the start, is unknown.

The frontal force that a sprinter exerts in starting in track has been studied by Henry (25), Henry and Trafton (27), and by Kistler (31). Vertical force could not be measured in any of these studies because the testing apparatus was designed so that only the one component force (frontal) could be recorded.

Force platforms have been used in the fields of industry, agriculture, and medicine, measuring forces by means of changes in electrical current. These platforms have been used to measure not only frontal forces, but also vertical and lateral forces. Barany (2) utilized a force platform and treadmill to study the walking gait of a hemiplegic patient. However, no studies were found which have validated this type of apparatus.

Cinematographical analysis has been used by several authors to study velocity, acceleration, movement, and angular position, in several athletic skills. Fenn (19), Beck (6), and Deshon and Nelson (14) studied various aspects of sprint running. Barth (5) studied the badminton backhand stroke, and Quandt (38) analyzed the velocity of two different baseball pitches.

No study was found which attempted to incorporate these two methods of analysis as a means of evaluating either the results obtained or the methods used.

II. THE PROBLEM

The purpose of this study is to analyze the different component forces, and their length and time of application, from the first recorded application of force until the swimmer clears the blocks for starts involving three different arm movements.

Sub-problems. It shall also be the purpose of this study to determine:

1. The relationship between impulses evaluated at selected points on the force curve, as measured by the force platform, and by cinematographical analysis.

2. The effect of the different arm movements on the movement time of the sprinter.

III. VALUES OF THE STUDY

The results of this study should have the following values:

1. This study should act as a pilot study in the use of the force platform (and related equipment) and cinematographical analysis and its role as a comparative measurement in studying movement.

2. With the lack of research and experimentation in the sprint start in swimming it is hoped that this study will provide the incentive for further investigation into specific and/or related problems.

3. The information should be of use to coaches and competitors by enabling them to understand better the starts and therefore enable them to plan their training more effectively.

IV. LIMITATIONS

This study has the following limitations:

1. The number of subjects selected (four) constitutes a small sample.
2. The subjects were selected on the basis of their experience and competence in competitive swimming and not in a random manner.
3. The study is limited to any errors inherent in experimental design, in the use of various measurement devices, and in the collection and interpretation of data.
4. In training the subjects in the three arm movements of the starts, the investigator may have introduced limiting factors within the individual subject.
5. Camera speed variance, and the effect of movement of the force platform table on the U bars are also limitations of this study.

V. DELIMITATIONS

The following delimitations must be taken into consideration when making inferences from this study:

1. The study is only concerned with frontal and vertical component forces, as exerted by the subject during the act of completing a sprint start in swimming.

2. The study is only concerned with the three arm movements and a constant, preferred, foot spacing for all three types of starts.

3. The study is only concerned with the movement time of the start. Reaction time is not included in any of the calculations.

VI. DEFINITION OF TERMS

Movement Time (M.T.). As used in this study movement time is the elapsed time in thousandths of seconds, from the first application of force on the starting block until the subject lost contact with the starting block.

Frontal Force (F.F.). Frontal Force is the component of force which is applied by the subject in a horizontal direction in the line of the start.

Vertical Force (V.F.) As used in this study vertical force is that component of force which is applied by the subject in a vertical direction.

Velocity (V). Velocity is the time rate of change of displacement of the mass centre of gravity.

Impulse (I). Impulse is the amount of force exerted multiplied by the time over which this force is exerted.

Mass (M.). Mass is the quantity of matter of the individual measured in pounds.

Sprint Start. For the purposes of this study sprint start will refer to the sprint start in swimming, unless otherwise stated.

CHAPTER II

REVIEW OF THE LITERATURE

I. INTRODUCTORY RESEARCH

Research pertaining to the sprint start in swimming is extremely meagre, with most of the studies having been conducted in the early World War II period.

Tuttle, Morehouse, and Armbruster (44), using 18 varsity swimmers, experimented to determine if starting blocks affected the starting time (the interval between the pistol shot and the time the swimmer left his mark). Using a starting block with angles of 10, 20, and 30 degrees, and the side of the pool, the swimmers were timed in milliseconds for an equal number of trials from each position, using their preferred stance. The construction of the blocks and the vertical distance between the top of the blocks, the side of the pool, and the water, were not given. Using odd-even correlation techniques these authors concluded that the blocks were a disadvantage, yielding slower starting times than trials from the side of the pool. One subject showed no significant differences in his starting time between either of the two methods of starting (side of the pool and the starting block).

In two further studies, these same authors (45,46) attempted to determine the optimum time for holding a swimmer on his mark. In the first of these studies ten All-American, or near All-American, calibre swimmers were used. A sound-key circuit was used to record the

time when the swimmer left his mark, thus providing a record of the starting time. A recording camera was used, with the holding times following a randomized order, and only legally defined starts were recorded. It was concluded that the longer holding times were preferable to the shorter times, with the optimum holding time being two seconds. The mean time for executing the start, after the stimulus (pistol shot), was .988 seconds. In a follow up study by these authors (46) it was determined that the trained swimmer left his mark .04 seconds faster than the untrained swimmer (.96 and 1.0 seconds, respectively).

Heusner (28), in studying the optimum angle of take-off in the sprint start, concluded that an angle of 13 degrees was the most efficient for starting. This angle was found to vary with the height of the blocks, the weight, gliding ability, swimming speed, and leg strength of the individual. Heusner also concluded that, with all other characteristics being equal, the swimmer with good vertical jumping ability would be able to swim a distance of 25 yards faster than the swimmer with poor jumping ability. This could be taken to mean that, with all other characteristics being equal, the person who can exert more force and obtain a greater velocity in starting should be faster over a given distance.

II. THE STARTS

Carlile (9:194) stated that:

> Whatever the position of the arms the important thing is that on the starting signal they must immediately swing

FIGURE 1

STEADY STANCE FOR THE ARMS BACK START.

FIGURE 2

STEADY STANCE WITH ARMS HANGING FROM SHOULDERS.

FIGURE 3

STEADY STANCE WITH ARMS HELD IN FRONT OF SHOULDERS.

> forwards, around and backwards. If there is any 'secret' of good starting then I believe that it is the immediate swing back.

Although Carlile has described the full arm circle start, he states that "I believe" that it is the "swing back" of the arms which is important to a good start. This "swing back" of the arms occurs in both the partial arm circle and the arms back starts.

Armbruster, Allen and Harlan (1:57) state that, "The weight of the body should be balanced on the balls of the feet with the heels only touching lightly." This describes the base of support, of the body, during the steady stance just before the occurrence of the stimulus.

The Arms Back Start. When the swimmer assumes his "steady stance" the arms are brought back as far as is comfortable (Figure 1). From this position, only a slightly upward movement of the arms are necessary to start the body forward. Once the body is projected forward, the legs can be brought into action. "The important feature of the arm action is the rapidity of the pitch forward, not the quantity of the momentum which is imparted" (1:63). Leaving the mark is divided into two parts:

a. The drop. The "drop" is that portion of the start concerned with shifting the centre of the body weight to a position in front of the base of support, so that the force applied will drive the body forward. Once this forward movement of the body has been initiated the arms swing "back and through", and when they are opposite the knees the drive portion of the start begins.

b. The drive. Powerful action of the legs and arms starts at this point during the start. The arms are swung forward until they reach a position just below eye level, and are fully extended. At this point they are brought to a sudden halt. This sudden stop transfers the forward momentum, of the arms, to the body. At the moment the arms stop, the ankles are snapped into extension, ". . . adding considerable force to the forward speed at the end of the drive." (1:66).

The Full Arm Circle Start. The arms in this start are designed to move the body forward with greater rapidity than the arms back start and also add force to the arms in both the "drop" and the "drive" positions. In the motionless "ready position", the arms hang loosely down from the shoulders with the elbows slightly flexed (Figure 2), or are held slightly in front of the shoulders (Figure 3). With the start stimulus the arms are moved forward with "tremendous speed" until they are just below shoulder level. The arms then continue forward, upward, and around in a circular sweep as the body drops. The arms are brought downward with great force until they reach a position adjacent to the knees where the "drive" portion of the start begins(1).

A major criticism of this type of sprint start is that ". . . the arms perform too great a range of movement to allow a fast start." (1:67).

The Partial Arm Circle Start. The steady stance on the block remains the same as for the full arm circle start, with the arms hanging loosely

from the shoulders or held slightly forward of the shoulders.

At the start stimulus the arms are swept forward, with maximum speed and force, until they reach a position just below shoulder level, in unison with this arm-sweep the hips and head are extended forward. Immediately after this level is attained by the arms, hips, and head, the elbows are bent and the arms are brought back until the hands are adjacent to, or slightly ahead of, the knees. From this position the arms are swept out, forward, and up with maximum force, in unison with the final extension of the knees and ankles. This puts the swimmer into a straight, stretched position for his flight and entry into the water.

III. FORCE PLATFORMS

Elftman (17), in 1938, appears to have been the first to use a force-plate to measure forces exerted by a subject. His apparatus consisted of two platforms, a series of compression springs, ball bearings, separate horizontal and vertical platforms, and recording levers, the deflections of which were photographed with a high-speed cin-camera to record the magnitude of the force.

In 1949, Lauru (cited in 4) built an instrument incorporating piezoelectric quartz crystals which emit electric impulses. These impulses were amplified and displayed on an oscillograph. The platform was a triangular design which enabled frontal (horizontal), vertical, and transversal forces to be measured.

Greene and Morris (22) designed a platform in 1959, using an equilateral triangular shape, supported by a frame which rested on steel balls on cantilever beams. The deflections in the cantilever beams were then transformed into electrical signals by means of Linear Variable Differential Transformers (LVDT) and a Universal Brush Analyzer was incorporated to record results.

Greene and Morris's platform was re-designed by Barany and Whetsel (3) so that it would be more portable but still retain all the essential features of the original design. The new platform had measurements of 25" x 22" x 5" and it was claimed that it could measure the heart-beat of a subject who was standing on it.

Marks and Herschberg (32) designed a force-plate apparatus incorporating two equilateral right triangles, cantilever beams and strain gauges, in an attempt to study hemipelegic gait.

Drillis (15), in 1958, designed a platform of two 15" x 20" aluminum rectangles, supported by hollow aluminum columns at each corner, and used strain gauges to measure the forces applied.

Barany (2) fitted the re-designed force-platform (3) into a treadmill in order to obtain the continuous walking forces of hemiplegic patients and used the following apparatus to convert the signals from the platform into digital data:

a. A four channel Dynograph recorder with three LVDT couplers and one AC - DC coupler.

b. Four voltage-to-frequency converters.

c. Six totalizing counters

d. A frequency period counter

e. A ten amplifier analog computor with four squaring function generators.

No record of use of this equipment to measure forces of sprint starts in swimming or track was found in a perusal of the literature.

IV. MOVEMENT TIME

Henry (25), in studying the sprint start in track, found that changes in block spacing influenced movement time, with longer block spacings resulting in a longer movement time. The longer movement time resulted because the larger the block spacing the greater was the length of time required for the front leg to clear the blocks. The greater length of time that the feet were in contact with the blocks resulted in slower starting times, but greater velocity was attained by the sprinter as he cleared the blocks.

Russell (41), using a sprint start block (designed by Dr. M. L. Howell) equipped with a transducer and differential transformer found that the partial arm circle start resulted in significantly faster movement times than either the full arm circle or arms back starts, following foreperiod delays of 2 and 3 seconds. The experimental group consisted of 12 males who were randomly assigned to the three start groups. These groups were given five hours of training, in their particular start, over a two week period.

Several authors (18, 21, 35, 39, 42) have found no correlation between movement time (speed of body movement) and reaction time.

V. CINEMATOGRAPHY

Cinematography as a method of analyzing body movement, forces and velocity has been used for a number of years. Fenn (19) studied track sprinters, Barth (5) analyzed the backhand stroke in badminton, and Quandt (38) the velocity of two different pitches in baseball. These studies serve to indicate the adaptability of cinematography.

In determining the position of the mass centre of gravity of an individual several authors (6,30,36) have found that the segmental method, as developed by Braune and Fischer (8) and later work by Dempster (13), and by Cooper and Glassow (12) proved to be a satisfactory method. The major disadvantage of this method of analysis appeared to be the amount of time needed to make segmental calculations.

A search of the literature revealed no studies which compared results obtained from cinematographical analysis with the actual results obtained from mechanical force measurements.

VI. GENERAL

The intensity of the stimulus and its effect on the reaction of the sprinter is not conclusively known. Griffith (24) stated that "the more intense the stimulus the quicker the reaction." However, Carson (10) did not find that the intensity of the stimulus (gun shot) was a determining factor in the starting time of a sprinter. Both these

experiments dealt with the sprinter in track.

Rarick (39) used 51 varsity athletes and physical education majors in an attempt to isolate certain common elements associated with speed of muscular movement. He concluded that:

1. Strength seemed to contribute little, if anything, to speed of performance when present in quantities greater than a certain minimum.

2. The part of the body weight not included in the skeletal musculature (dead weight) appeared to act as an opposing force to speed of muscular movement.

3. Latency of muscle response seems to exert no significant influence on speed of movements.

Pierson (37) stated that the speed with which an untrained individual can react had little relationship to body size or composition.

CHAPTER III

METHODS AND PROCEDURES

I. THE SUBJECTS

The subjects were four competent male swimmers with competitive swimming experience ranging from 4 to 10 years. All subjects were selected volunteers ranging in age from 17 to 27 years, three being university students and one a senior in high school. None of the subjects normal activities or training was restricted in any manner during training for this study.

II. APPARATUS

As several pieces of equipment were used, either singly or in a combined sequence, each will be explained separately and then a summary of their total relationship will be presented.

Force Platform (Figure 4). The force platform was of all metal construction with the exception of the surface bed which was made of 3/4 inch plywood. The platform was constructed in the shape of an equilateral triangle. The following items enabled the measuring of forces by means of electrical impulses:

a. U Bars: The U bars are used to support the bed of the platform on the base, as well as provide the surface upon which strain gauges were affixed. Each U bar was adjustable so that the amount of force applied to each U bar could be restricted. The design of each U bar, however, was such

FIGURE 4

SIDEVIEW OF FORCE PLATFORM WITH STARTING BLOCK MOUNTED ON PLATFORM BED.

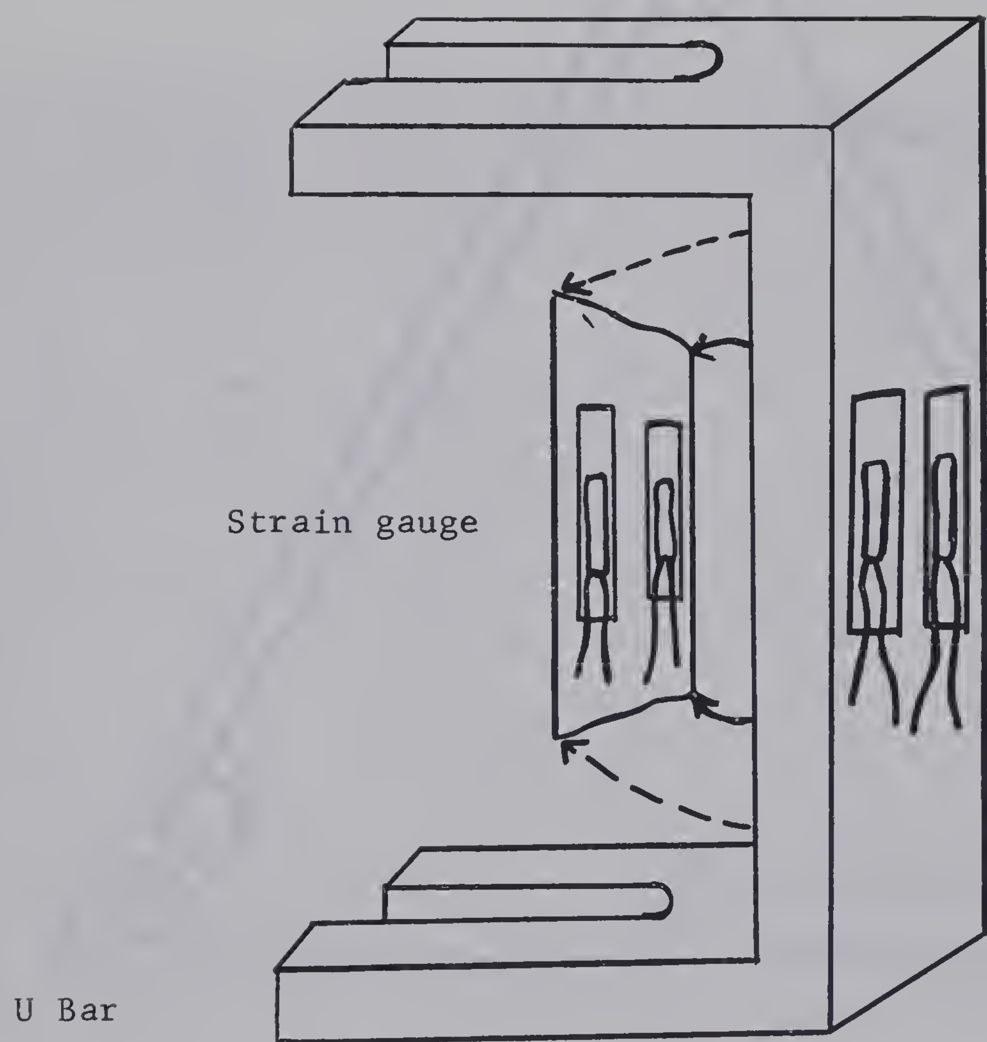


FIGURE 5

STRAIN GAUGE MOUNTINGS ON U BAR (40)

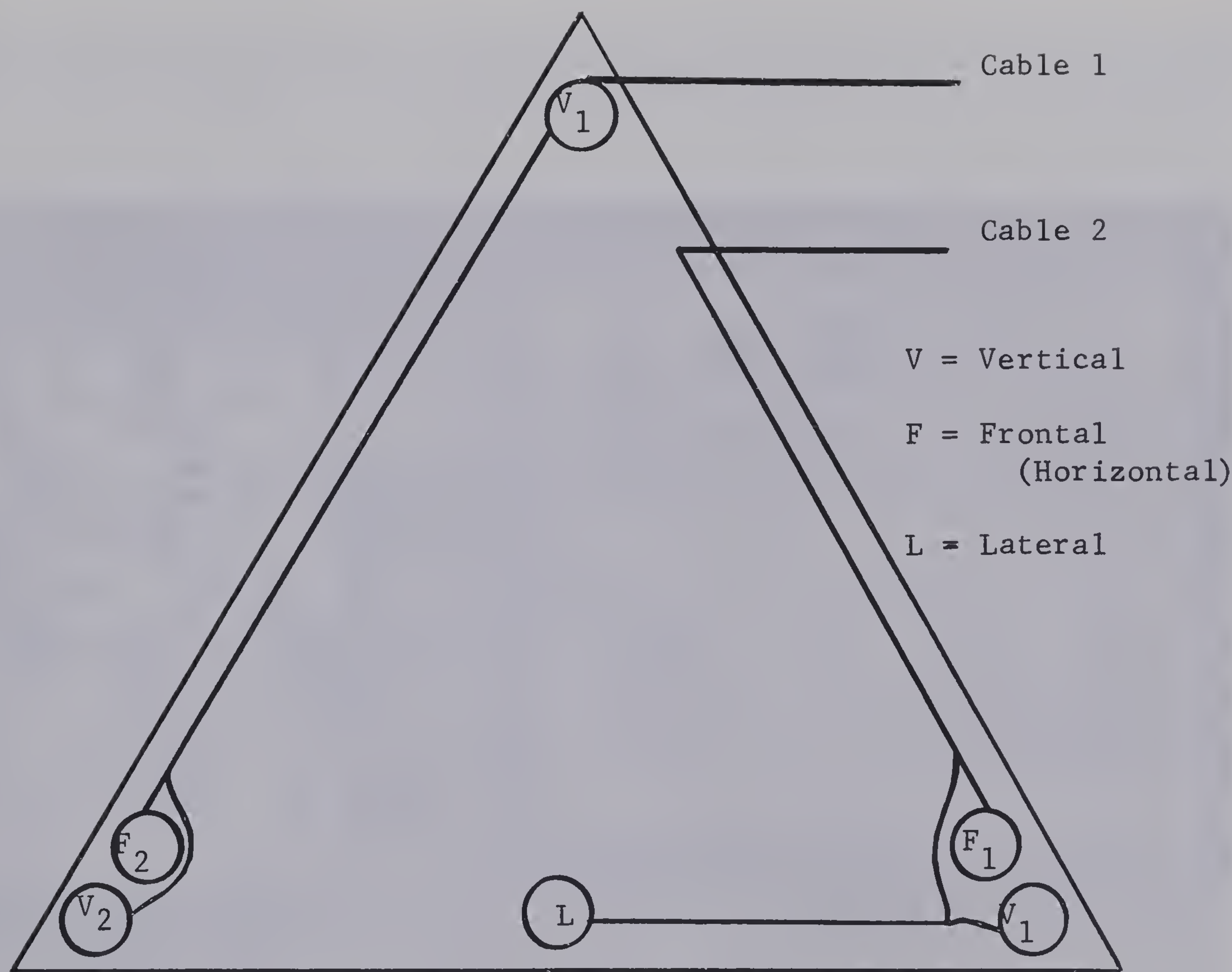


FIGURE 6

STRAIN BAR AND CABLE ARRANGEMENT

OF FORCE PLATFORM (40)

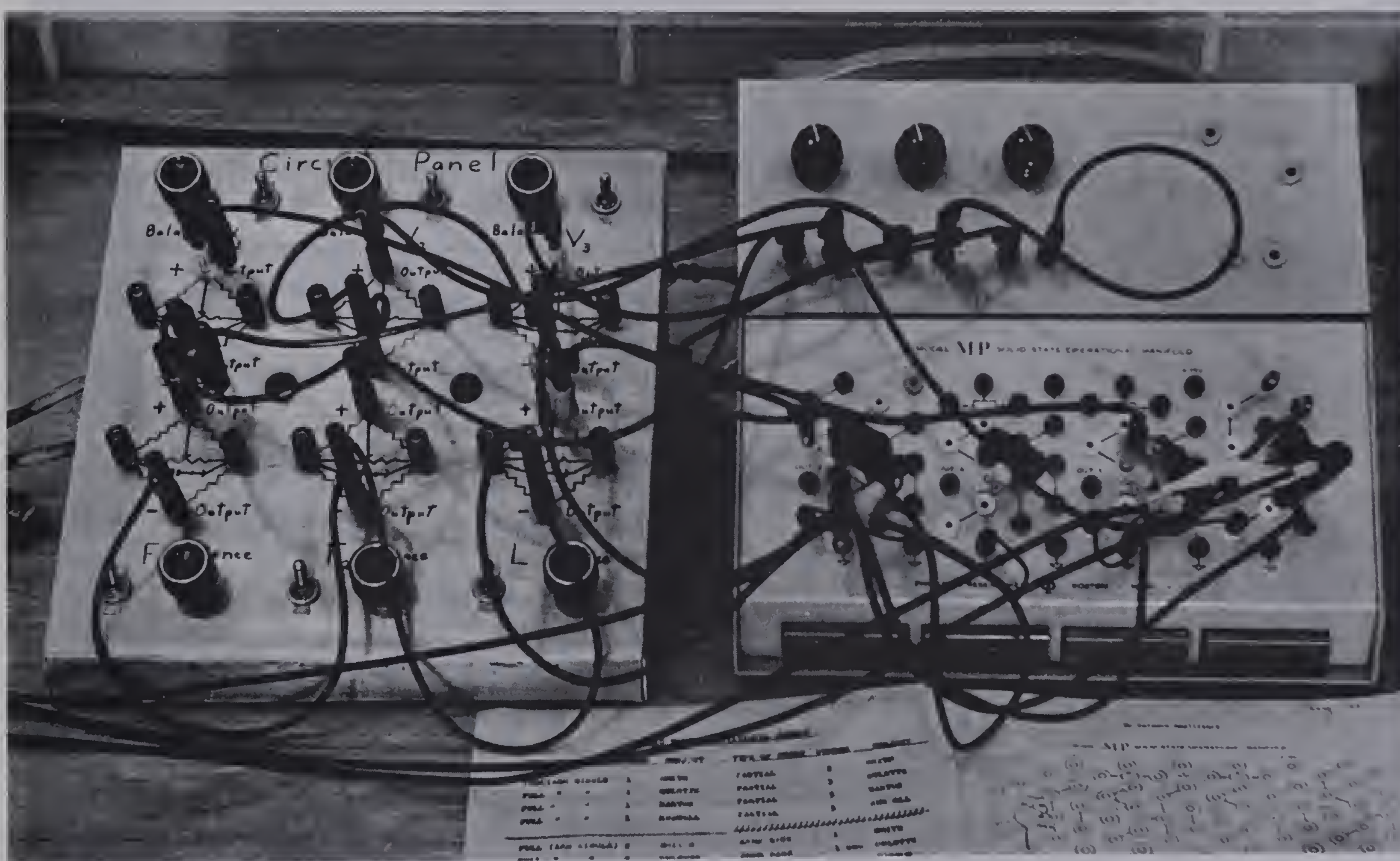


FIGURE 7

CIRCUIT PANEL AND PHILBRICK OPERATIONAL AMPLIFIER, SHOWN DURING TESTING.

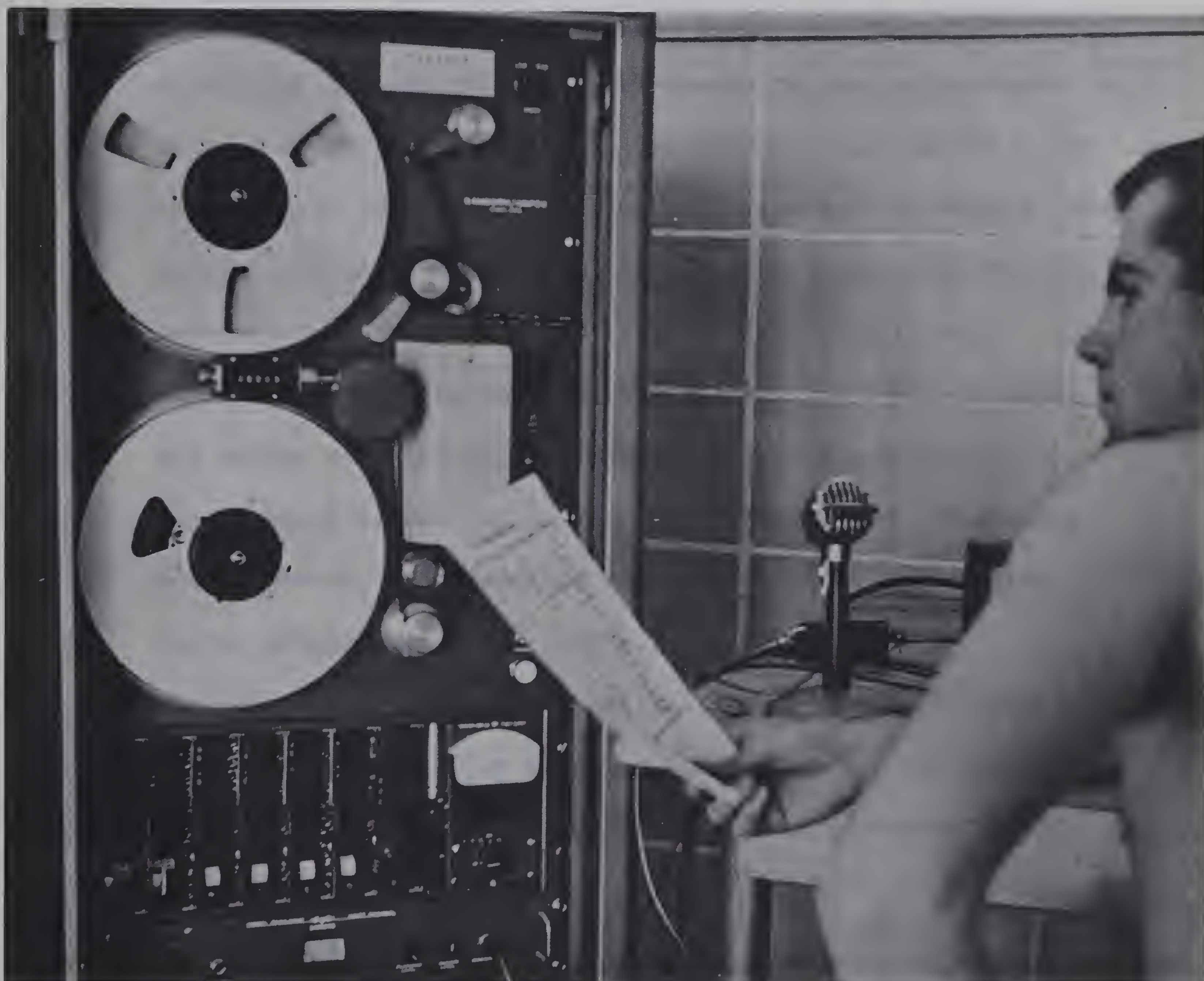


FIGURE 8

SANBORN MODEL 2000 SIX-CHANNEL MAGNETIC TAPE RECORDER.

that a maximum load of just under 200 pounds at 1.2 inches from the centre of the bar could be measured (Figure 5).

b. Electrical Output: Wheatstone bridge circuits were made up of four 500 ohm strain gauges bonded to the two surfaces of each U bar. The bridge circuit was connected at the U bar so that only four leads left each U bar instead of eight. There were six of these bridges in the platform, measuring the appropriate component forces (Figure 6). These bridges were balanced before each testing session. Electrical input and output connections were completed by using a circuit panel. Each bridge had an individual switch and a balancing potentiometer. The platform was calibrated by using either static weights or spring scales.

Operational Amplifier (Figure 7). A Philbrick Model MP self-powered four stage operational amplifier was used to amplify and sum the impulses, from the platform and circuit panel, before they were recorded. The amplifier was basically a self-contained instrument with a front panel of amplifier input, output, and common terminals brought out to multiple tip jacks.

The impulses from the operational amplifier could be permanently recorded by a Sanborn Model 2000 six-channel magnetic tape recorder (Figure 8): this recorder also had a voice channel which the operator used to record the subject's name, type of start, and the number

of the trial before each trial began as well as any other pertinent information that resulted throughout the testing period.

Brush Recorder. A dual channel model Mark II Brush Recorder was used to obtain permanent paper graphs of the readout from the magnetic tape. This machine graphically recorded electrical impulses by means of an ink marking pen on recording paper. A volt/chart line setting of .01 volts/cm. and a paper speed of 125 mm./second were used in this study.

Starting Block. The starting block was constructed of 3/4 inch plywood, 25 inches wide by 15 inches deep by 8¼ inches high, with a corrugated rubber top and a rule scale (in ½ inch increments) marked on the front edge. The starting block had metal angle braces securely fixed at the bottom of three sides so that it could be mounted on the wooden bed of the force platform with wood screws.

When the starting block was mounted on the force platform (Figure 4, page 18), the top of the block was 15 3/4 inches above the pool deck, and 27½ inches above the water surface. The height of 27½ inches for the starting block was within the maximum allowable distance of 30 inches, therefore conforming to the rules of international competitive swimming.

Platform Stabilizer. The stabilizer was designed to attach over the two forward feet of the force platform and to hold it stationary on the pool deck surface. The existing permanent deck inserts were used to secure the stabilizer to the deck surface.

Two flat steel bars, ½ inch thick and 3 inches wide, were constructed so that one end fitted over the metal foot plate and around the leg of the force platform and extended 10 inches past the deck insert at the other end. Each bar was equipped with a bolt which could be fitted into the deck insert and tightened. To avoid any possible sideward movement of the platform, a ½ inch square steel rod was attached to one stabilizer bar and was passed through a bridge and locking wing bolt on the other stabilizer bar.

Operational Summary of Force Platform Apparatus. Once the force platform had been secured to the pool deck the leadout from the strain gauges was connected to the circuit panel. The circuit panel was connected to the operational amplifier (See Appendix B), which amplified and summed the impulses from the individual wheatstone bridge circuits, before transferring the impulses through the input leads to the Sanborn Model 2000 Magnetic Tape Recorder for recording. The Sanborn Recorder had six recording channels and one voice channel, which was connected to a microphone. Due to the amplifying and summing function of the operational amplifier only two recording channels were utilized. All verbal information and directions were recorded on the voice channel.

Permanent recording graphs of the data were obtained by connecting the output channels of the Sanborn Recorder to the Brush Recorder, Model Mark II. All pertinent information from the voice channel was transferred manually to the permanent graphs at that time.

Cinematography. For the filming of the starts, a Bell and Howell 16 mm. model 70-HR camera with a 15 mm. wide angle lens was mounted on a tripod, pointed at right angles to the line of start, and 16 feet from the starting block. A four foot by eight foot rectangle of plywood, painted white with black lines marked off in six inch squares, was held in place on the starting block at the start, middle, and end of the testing period. The filming of this board enabled an accurate measurement of distance in the film frame as well as providing a means of eliminating any lens distortion which might have occurred within the filming of the start trials. Several trial starts were filmed so that camera position and operation could be accurately adjusted.

As the camera was spring driven, a chronoscope was filmed at the start, middle, and end of the testing period so that the actual shutter speed of the camera could be determined to the nearest millisecond. The camera was rewound after every third trial during the testing period.

For each trial the camera was started with the starter's command, "Take your marks", so that the camera would be at its full running speed by the time the stimulus (gun shot) was sounded. The camera was stopped when the subject entered the water. A record of the subject's name, the type of start, and the trial was included in the film by putting this information on a white sheet of paper and placing it on the force platform. This enabled the investigator to analyze only the actual trials and to eliminate all false starts.

III. TRAINING PROCEDURE

Each subject individually trained for a total of six hours over a five week period. During each training session the subject was required to practice all three types of starts from one of the regular starting blocks. Regular competitive race commands were used, but a voice stimulus was substituted for the gun shot.

General and specific criticisms were made before and after each practice start. Dry land practice, in order to correct mistakes or learn new techniques, was utilized wherever possible. Emphasis, in the form of more practice time, was given to the type, or types, of start which required the most improvement.

IV. TESTING PROCEDURE

The force platform was secured to the deck of the pool and enclosed with a polythene sheet to prevent water from interfering with the measuring devices. The starting block was then secured to the platform bed and all electrical connections were made and tested. The total apparatus was demonstrated and explained to the subjects and each executed several dives from the starting block in order to familiarize themselves with it. During these preliminary dives each subject determined and noted his preferred foot spacing on the block.

The testing procedure and order of testing were then explained. The commands to be used and the stimulus (gun shot) were also demonstrated. The subjects were reminded that all rules of starting as outlined by F.I.N.A. (the International body of Competitive Aquatics) would be

observed, and that only legally defined starts would be recorded. A set order of testing was established prior to the testing period and copies of this order were supplied to the starter, the recorder operator, and the subjects (See Appendix A).

When the subject was called for each trial the recorder was started and the subject's name, type of start, and trial number were recorded on the tape. The subject then mounted the block and stood upright until the starter (experienced and qualified as a starter in competitive swimming) gave the command "Take your marks". In conjunction with this command the photographer started the camera, and the subject assumed his "steady start position". When the starter, positioned about eight feet to one side and slightly behind the subject, was confident that the steady stance had been attained, the starting stimulus (gun shot) was given. After the subject had completed that trial the camera was stopped, any pertinent information was included on the voice channel of the tape recorder and the recorder was stopped.

The subjects were required to sprint several strokes after each trial, and were reminded to check their foot spacing upon mounting the block. All false starts were retaken before continuing with the next subject's trial.

V. METHOD OF ANALYSIS

Force Graphs. The permanent force graphs obtained by the Brush Recorder readout from the magnetic tape recording of the force platform impulses were analyzed for movement time, frontal and vertical velocity, and

impulse.

Movement time. As the recording paper was marked in millimeters, the movement time for each trial was calculated by determining the distance between the initial recorded force movement and the point where the recording pen returned to the baseline, this was assumed to be at or immediately after the subject left the block at the end of the start. In order to re-convert this tape distance from millimeters to time in thousandths of seconds, the calculated number of millimeters was divided by 125 (the paper speed of the Brush Recorder was set at 125 mm/second), and taken to three significant decimal places.

Velocity. The frontal and vertical velocities were determined with a Coradi Compensating Planimeter, Cora-Senior type, which was used to calculate the area under the curve (in square inches). For convenience of calculation the obtained values in square inches were changed to square millimeters by multiplying by 645.16 (1 square inch = 645.16 square millimeters).

Velocity was calculated from the formula $V = \frac{FT}{M}$, where FT is the impulse and M is the mass of the subject in slugs. Impulse per square millimeter was calculated from the calibration graphs of the force platform using the formula X lbs. x 1/125 seconds, where X is the pounds force required for a pen deflection of one millimeter. Thus impulse (I) for each trial was calculated by multiplying the total area (in square millimeters) by the impulse per square millimeter. In order to obtain the velocity (V), the impulse was divided by that subject's

mass (M).

Since an indication of the total positive velocity was desired, negative areas of the curves (area beneath the baseline) were subtracted from the positive area before being submitted to further analysis. The baseline for the vertical velocities was determined as the amount of recording pen deflection produced by the subject in this "steady stance".

Impulse. Impulse was determined with a compensating planimeter, as outlined in the previous section on velocities. The compensating planimeter was used to obtain the total impulse for the graph of each trial as well as to obtain separate defined portions of the Type III starts.

The separate defined proportional impulses were required so that a correlational comparison with corresponding impulses determined by cinematographical methods would be possible. It was assumed that the point on the baseline of the Brush Recorder graphs where the recording pen returned as the subject cleared the block was the same point in time as the instant when the subject's toes were shown to have left the block in the films. Therefore, time points were determined on the graph baseline, starting from the end of the recording rather than the beginning. A line perpendicular to the baseline was drawn at each of these determined points and the impulse enclosed within any two of these perpendicular lines could be determined with the compensating planimeter.

Cinematography. The mass centre of gravity of each subject was determined by the segmental method as outlined by Braune and Fischer (8) and by Dempster (13). Start analysis is retrospect from the frame where the subject's toes were last in contact with the starting block, and for frames 3, 5, 7, 11, 15, 19, . . . until reaching the frame where the first body movement commenced were determined for all start trials, with a plus or minus 3 frame accuracy error in determining the first body movement. The joint centres (reference points) were plotted on semi-transparent copy paper directly from the film frame, enlarged with a Remington-Rand Microfilm Viewer. Several reference lines, both horizontal and vertical, were also included on each page so that the plotting of the path of the mass centre of gravity throughout each trial could be accomplished.

The Segmental Method. This method of determining the mass centre of gravity utilizes the centres of gravity of the body segments, which occur a certain percentage of the distance between two reference points (joint links). The percentage of the total body weight that each segment occupies, and the location of the centre of gravity for each segment, as determined by Dempster (13), were used in this study.

For all segments for each subject (except the upper limbs) a series of eight frames were taken and the length of each segment was determined for each of the eight frames. The mean of the eight measurements (for each segment) was then used as the distance that the

segmental centre of gravity was to be found in all further analyses. As the arms rotated around the shoulder blade and therefore were not always vertical to the camera, the segmental centres of gravity for the upper limbs had to be calculated separately for each frame analyzed

The segmental centres of gravity were marked on a line drawn between each of the reference joint centres, then lines were drawn from each of the centres to a constant horizontal and vertical reference line for that frame (the edges of the paper were used). The distance that each of the segmental centres of gravity was from its vertical reference line was measured to the nearest half millimeter. This distance was then multiplied by the weight of that particular segment. When this value was obtained for each of the seven segments their sum was obtained and then divided by the total body weight for that subject. The obtained value was the distance that the mass centre of gravity was from the vertical reference line. When this procedure was applied to the horizontal reference line the distance that the mass centre of gravity was from the horizontal border was obtained. Lines were plotted for these two values and these two axes crossed where the mass centre of gravity would be found for that individual and that frame.

The segmental percentage distances of the total centres of gravity per body segment and percentage of total body weight found in each segment are given in Table I (13).

TABLE I

SEGMENTAL CENTRES OF GRAVITY AND PERCENTAGE OF TOTAL BODY WEIGHT FOR EACH SEGMENT

Segment	Percentage of Centre of Gravity from Reference Joint		Percentage of Total Body Weight
Head, neck, and trunk	39.6	from hip joint	59.0
Arm	43.6	from shoulder joint	2.7 x 2
Forearm	43.0	from elbow joint	1.6 x 2
Hand	50.6	from wrist joint	0.6 x 2
Thigh	43.3	from hip joint	9.7 x 2
Leg	43.3	from knee joint	4.5 x 2
Foot	42.9	from ankle joint	1.4 x 2

For the calculated segmental weights for each subject refer to Appendix C.

Velocity. In order to obtain the velocity, the mass centre of gravity for each frame analyzed was plotted on one page and the horizontal distance (to the nearest 0.5 mm) that the mass centre of gravity travelled between plots was measured. The cumulative horizontal distance travelled by the mass centre of gravity, and the time taken to travel this distance, were plotted on graph paper. From this graph

and the cumulative horizontal distance and time, the velocity for any given time during the start could be determined by the formula $V = d/t$, where d is the distance travelled and t is the time taken to travel that distance.

Time per film frame was determined by counting the number of frames for one second of filming of the chronoscope and dividing this number of frames into 1 to obtain the time per frame for that segment of the film.

In order to convert the velocity from millimeters per second to feet per second the number of millimeters that were equal to one foot had to be determined. This was calculated by measuring the number of millimeters equal to six inches from the film of the scaled four foot by eight foot plywood sheet that was filmed for lens distortion.

Impulse. To determine the impulse from the cinematographical data the formula $I = M \times \Delta v$ was used. Impulse (I) being equal to the mass (M) times the increase in velocity between time 1 and time 2 (Δv). These impulses were cumulated and compared with the cumulated impulses determined from the graphs of the force platform readout.

VI. STATISTICAL TECHNIQUES

The results calculated either from the Brush Recorder graphs of the readouts from the force platform recordings, or by cinematographical analysis, were submitted to one of the following tests:

1. Analysis of Variance. The analysis of variance treatment

(20:292) was applied to the different parameters in order to determine if there were any significant differences between the three types of starts. The parameters submitted to this analysis were: movement time (M.T.), frontal velocity (F.V.), and vertical velocity (V.V.).

2. <u>Pearson Product-Moment Correlation Coefficient</u> (20:111). This test of correlation between parameters or methods was used to determine the relationships between the frontal velocity and movement time for each of the three types of starts. The correlation between corresponding cumulative impulses as calculated from the force platform graphs (using a compensating planimeter) and as calculated by cinematographical techniques was also determined.

CHAPTER IV

RESULTS AND DISCUSSION

I. RESULTS

Force Platform Calculations.

The mean group movement times, positive frontal velocities, and positive vertical velocities are represented in Table II. Reproductions of actual representative frontal and vertical force graphs for start Types I, II, and III, are shown in Figures 9, 10, and 11 respectively.

TABLE II

MEAN GROUP MOVEMENT TIMES, AND POSITIVE FRONTAL AND VERTICAL VELOCITIES FOR THREE TYPES OF SPRINT STARTS IN SWIMMING

Start	Movement Time in Seconds	Frontal Velocity in Ft/sec.	Vertical Velocity in Ft/sec.
Type I	.836	16.236	.419
Type II	.852	16.330	.547
Type III	.887	16.340	.600

Measurement of Movement Time. The mean movement time (M.T.) for three trials for each subject was calculated (See Appendix C). A one-way analysis of variance between the three types of starts revealed

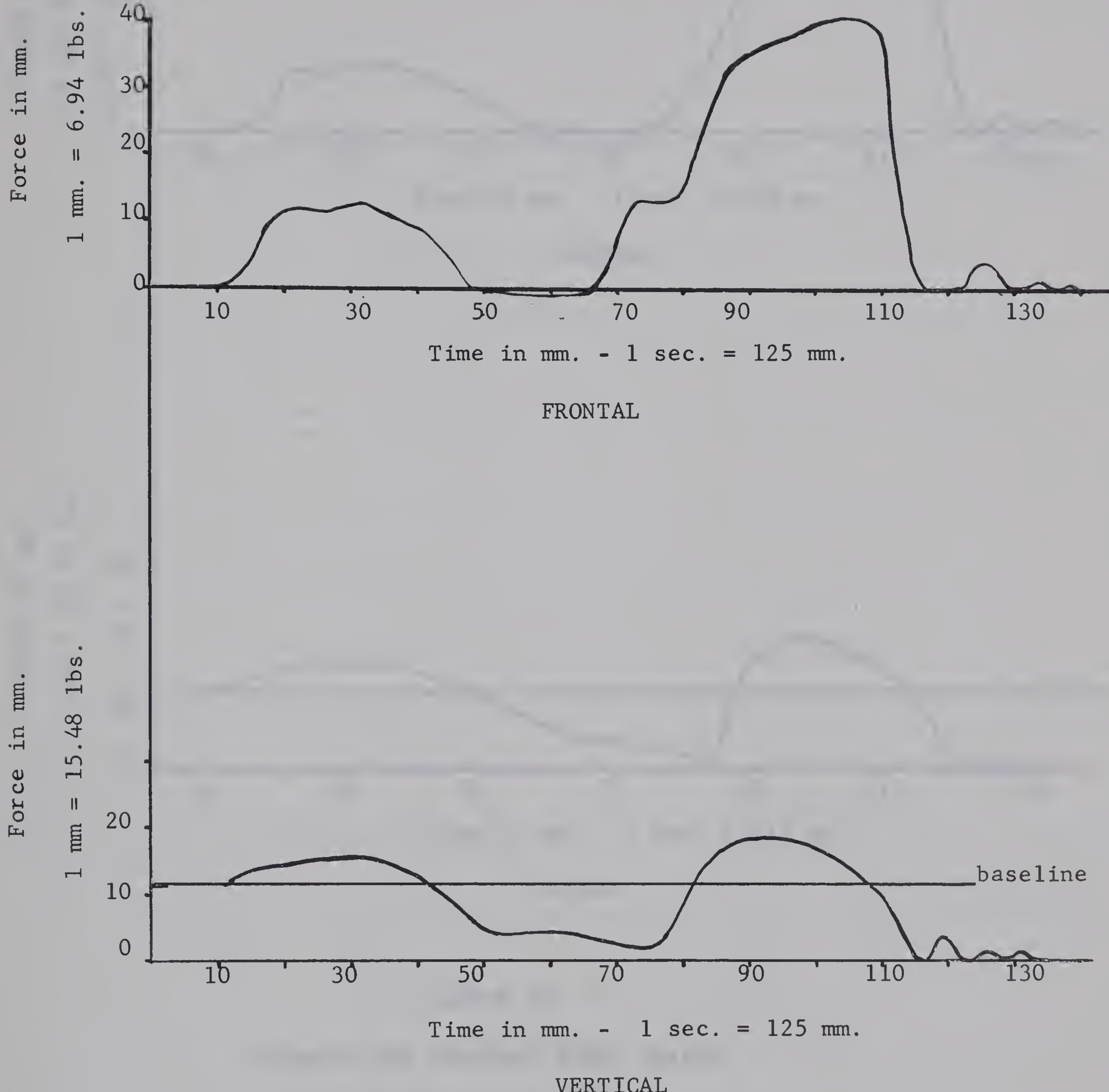


FIGURE 9

FRONTAL AND VERTICAL FORCE GRAPHS

FOR TYPE I SPRINT START

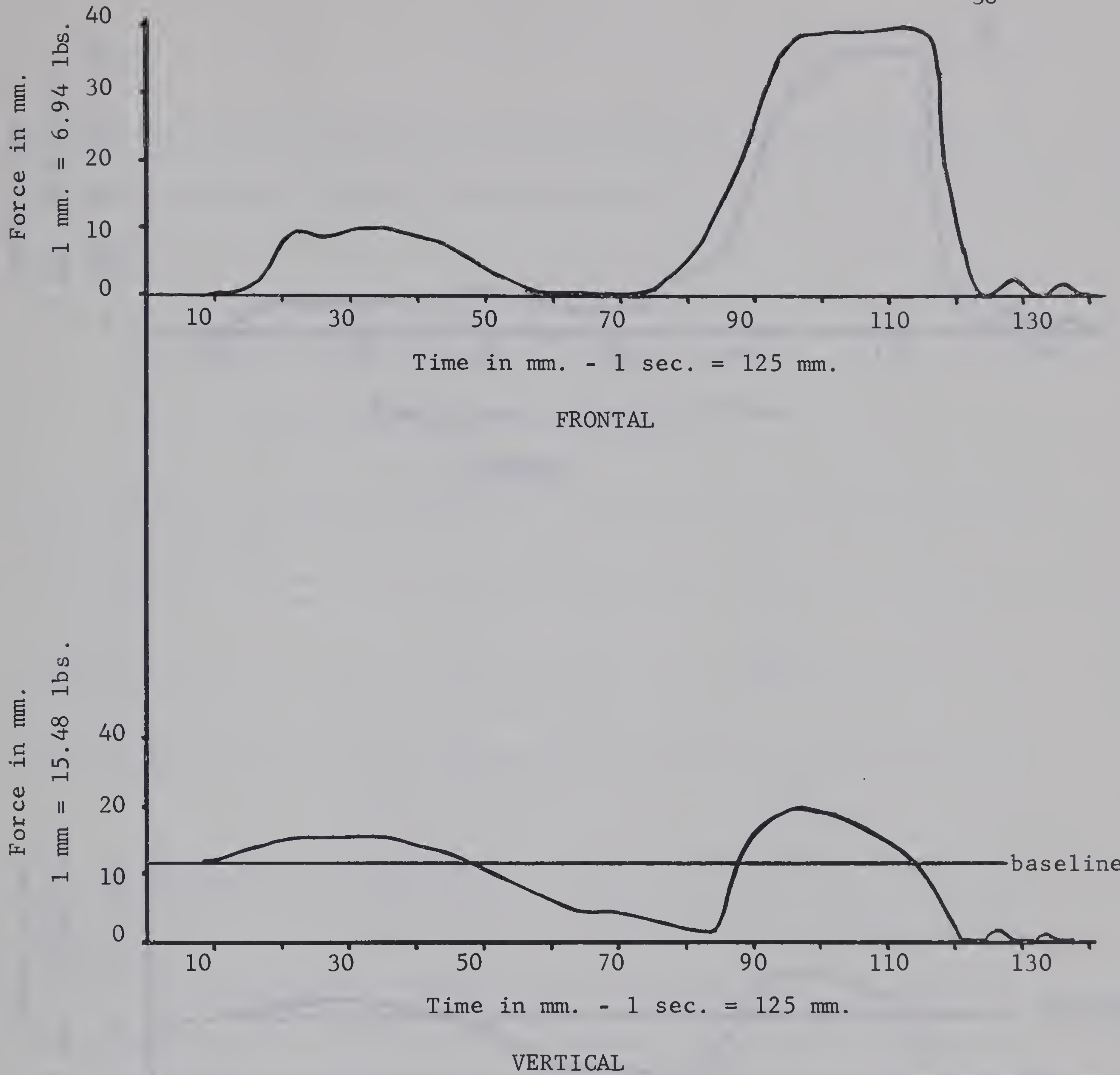
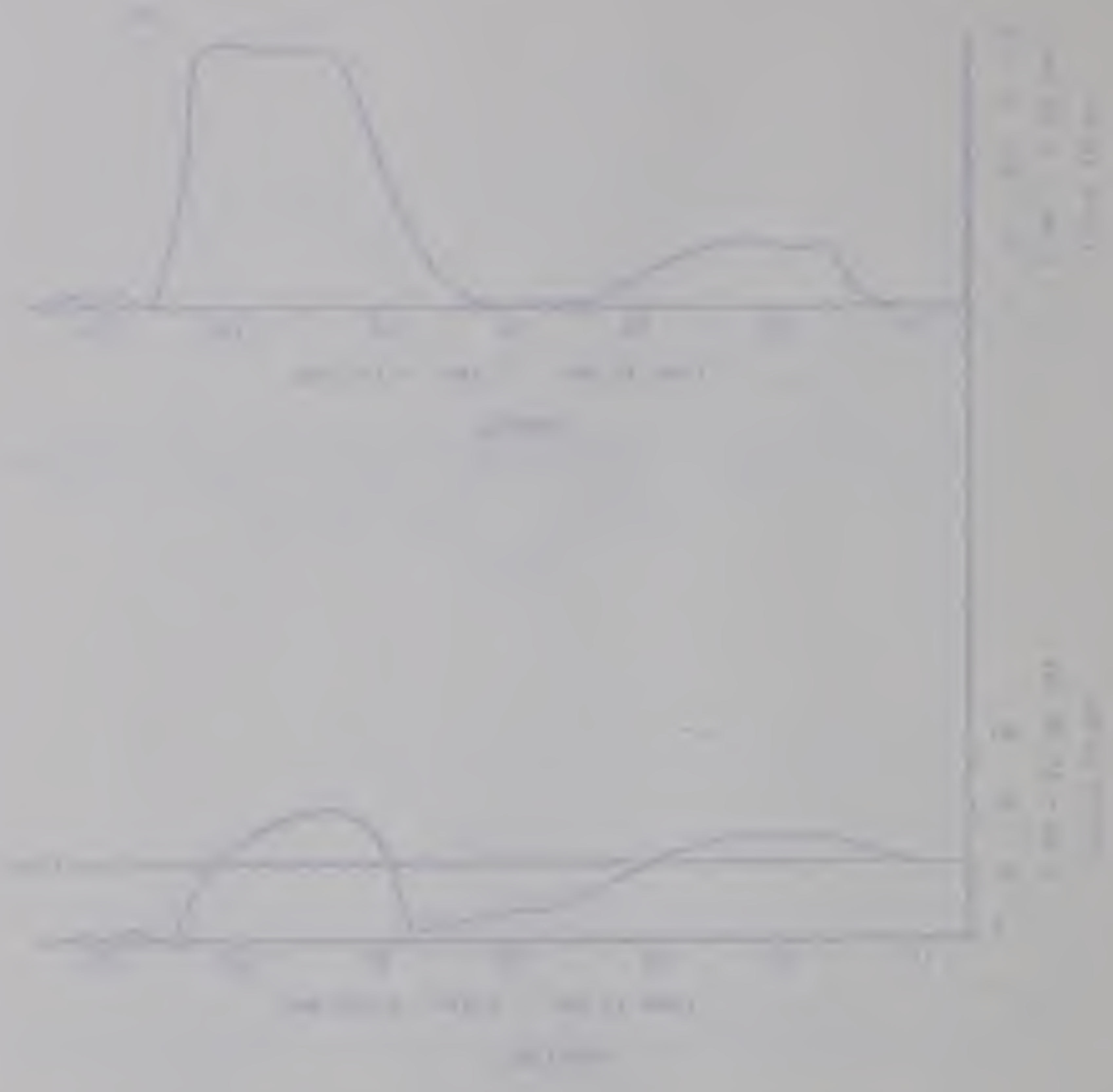
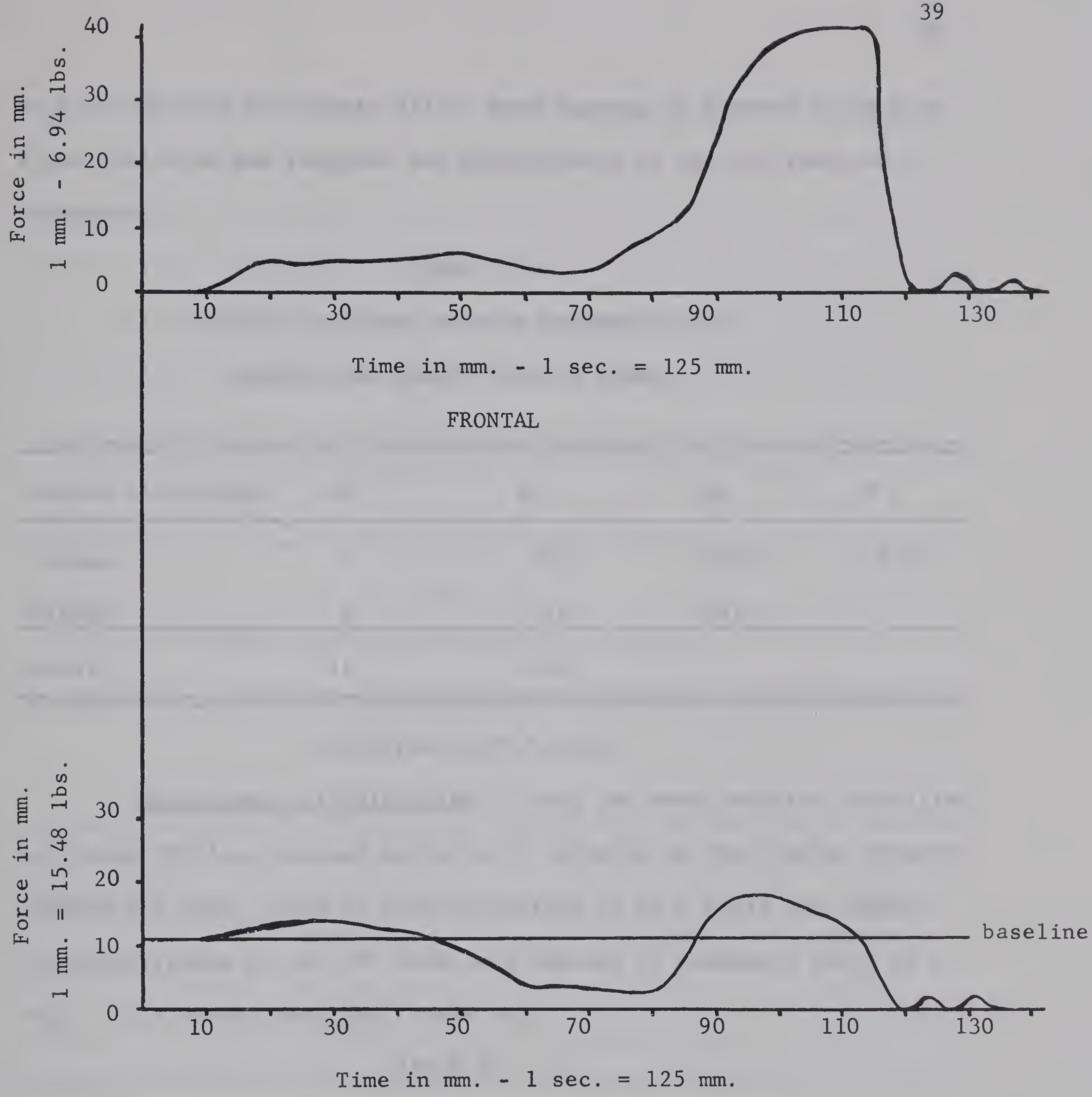


FIGURE 10

FRONTAL AND VERTICAL FORCE GRAPHS

FOR TYPE II SPRINT START





VERTICAL

FIGURE 11

FRONTAL AND VERTICAL FORCE GRAPHS

FOR TYPE III SPRINT START

an F ration of 0.833 (Table III). With degrees of freedom 2 and 9 an F ratio of 4.26 was required for significance at the .05 level of confidence.

TABLE III

VARIANCE ANALYSIS OF MEAN MOVEMENT TIMES BETWEEN THE THREE TYPES OF STARTS

Source of Variance	df	SS	MS	F
Between	2	.002	.0010	0.833
Within	9	.011	.0012	
Total	11	.013		

F.05 (df. 2,9) = 4.26

Measurement of Velocities. Using the mean positive velocities for three trials, a one-way analysis of variance of the frontal velocity between the three types of starts resulted in an F ratio of .00067. For significance at the .05 level and degrees of freedom 2 and 9 an F ratio of 4.26 was required (Table IV).

TABLE IV

VARIANCE ANALYSIS OF MEAN FRONTAL VELOCITIES BETWEEN THREE TYPES OF STARTS

Source of Variance	df	SS	MS	F
Between	2	.018	.009	.00067
Within	9	120.024	13.338	
Total	11	120.042		

F.05 (df. 2,9) = 4.26

The calculated positive vertical velocities were small, with four trials showing negative vertical velocities for one subject (See Appendix C). These velocities were submitted to one-way analysis of variance. No significant differences were found between trials for either Type I (fu ll arm circle), Type II (parial arm circle), or Type III (arms back), revealing F ratios of 0.444, 1.543, and 0.008, for three types of starts, respectively. With degrees of freedom 2 and 9 in all three calculations F ratios of 4.26 were required for significance at the .05 level of confidence (Table V).

TABLE V

VARIANCE ANALYSIS OF VERTICAL VELOCITIES BETWEEN TRIALS FOR GROUP COMBINED FOR EACH TYPE OF START

Type of Start	df	SS	MS	F
I	2/9	13.277/134.69	6.639/14.966	0.444
II	2/9	27.435/79.987	13.718/8.887	1.543
III	2/9	25.19/13,881.46	12.595/1542.38	0.008

F.05 (df. 2,9) = 4.26

Frontal Velocity-Movement Time Correlations. Pearson product-moment correlation coefficients (20) were calculated to determine if any correlation existed between the positive frontal velocity and the movement times for each type of start. Using the mean velocities and

movement times of the three trials for each subject, correlations of -.388, +.129, and -.756 were obtained for start types I, II, and III respectively (Table VI).

Correlation of Impulses. The arms back start (Type III) was selected to compare the force platform impulse values, with those obtained by the cinematographical techniques used in this study. A Pearson Product-Moment correlation coefficient comparison was calculated for this comparison.

The cumulative impulse (I) calculated cinematographically was compared with the cumulative impulse (I) of the platform readouts calculated using a compensating planimeter. The common reference point was that instant when the subject cleared the block, therefore, the cinematographically determined impulses and times began at this point (t_o) and proceeded in reverse direction to that of the actual trial start. Comparative reference times and areas were plotted on the recording readout graphs in the same reverse sequence from the common reference point.

The calculated correlation coefficients for each time (t) are given in Table VII. The highest correlation (.697) occurred at time t_5, with times t_1 to t_4 giving the lowest correlations ranging from .113 to .404. The total cumulative impulse (t_n) for each of the two methods resulted in a correlation of .537.

TABLE VI

PEARSON PRODUCT-MOMENT CORRELATIONS BETWEEN FRONTAL VELOCITIES AND MOVEMENT TIMES FOR THREE TYPES OF STARTS

Type of Start	Sum Frontal Velocity	Sum Movement Time	r
I	64.943	3.345	- .388
II	65.318	3.406	+ .129
III	65.358	3.547	- .756

TABLE VII

PEARSON PRODUCT-MOMENT CORRELATION BETWEEN FRONTAL FORCE IMPULSES DETERMINED FROM FORCE PLATFORM GRAPHS AND CINEMATOGRAPHICAL ANALYSIS FOR TYPE III STARTS.*

TIME	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_n
Number of Trials	12	12	12	12	12	12	12	12	11	12
Correlation r	.298	.281	.113	.404	.697	.431	.417	.555	.513	.537

*Corresponding times determined from end of starts and calculated in reverse direction, toward beginning of start.

II. DISCUSSION

As three different experimental treatments, for a correlated sample, were used in this study, a one-way analysis of variance was used to test for the significance of differences between the treatment means. Variance analysis was used by Henry (25) in studying the force-time characteristics of the sprint start in track, and by Russell (41) in studying force-time characteristics of the sprint start in swimming.

One of the purposes of this study was to compare the impulses calculated from the force platform graphs with those obtained from cinematographical analysis of the same start. The Pearson Product-Moment correlation coefficient was utilized to determine the relationship that existed between these two methods of measurement.

Movement Time (M.T.). The mean movement times for the three experimental starts indicated that no significant differences existed between them. The F ratio of 0.833 which resulted was far below the F ratio of 4.26 (df. 2,9) which was required for significance at the .05 level of confidence.

Therefore, within the limits of this study, it would appear that any differences which exist in movement times between the three types of starts is minimal, at least when the mean of three trials for each start are compared. These findings are consistent with those of Henry (25) who examined movement time in the sprint start in track. In a previous study using naive swimmers trained on one type of start for a total of five hours over a two week period, the author found the movement time of the partial arm circle start to be significantly

faster than either the full arm circle or arms back starts. Several possible reasons for this significant difference were offered, with the greater difficulty in learning to fully use the arms in the partial arm circle start probably being of major importance.

The results of this study indicate the possibility that a well trained competitive swimmer's movement time will be affected very little, if any, by the type of start which he employs.

Velocity. Henry (25:302) stated that force, and as a result velocity, was more important than starting time in a fast sprint start. Therefore, following this view, it would seem that the start which generated the most velocity would be the superior start.

The results obtained from the variance analysis of the mean frontal velocity and vertical velocity indicate very little differences either between start types I, II, and III (for frontal velocity) or between trials for the vertical velocities. Therefore, on the basis of this study, it must be concluded that the subjects all leave the blocks with relatively the same mean positive velocities, regardless of the type of start.

As mean positive velocities were analyzed in this study it would logically follow that any possible increase in the total positive velocity for the subject might occur with the reduction of negative velocities. The reduction of the negative components both in the type of start, and in the individual's execution of the start, is one area in which research and coaching can be mutually beneficial to each other. Howell (29) found that the use of force graphs, and a knowledge

of their results, significantly improved a competitor's performance.

Frontal Velocity-Movement Time Correlations. The product-moment correlation coefficient values obtained indicate very little predictability of velocity from a knowledge of the movement time.

An r value of -.388 indicated an inverse predictability of frontal velocity from a knowledge of the movement time, for the full arm circle start (Type I). For Type II starts a correlation value of +.129 indicated almost no predictability of frontal velocity from a corresponding knowledge of the movement time. A high negative correlation (r =-.756) between frontal velocity and movement time for Type III starts indicated that as movement time increased the frontal velocity decreased.

Although these correlations are spurious, because movement time is an incorporated part of velocity, the high negative correlation for Type III starts indicates that further study is required to determine if this relationship is in fact a true relationship, and if so, why does it occur?

Correlation of Impulses. In order for a force platform to be of research value in athletic fields it must, of necessity, be known if it measures what it was designed to measure. The environmental and situational difficulties in measuring sprint starts are many, therefore, evaluation of any experimental apparatus is magnified by these difficulties.

Cinematographical analysis has been utilized by several authors (5, 19, 30, 36, 38) to analyze velocity, speed of movement and/or mass centre of gravity of different total or partial body movements. This

method of analysis was selected for this study because it was extremely adaptable to adverse testing situations.

The cumulative impulses (determined in reverse direction to the actual start) were calculated from the force platform readout graphs and correlated with the cumulative impulses calculated from cinematographical data. The highest coefficient (r = .697) occurred at time t_5. This time included the major portion of the frontal force accumulated from the beginning of the "drive" portion of the start until the completion of the start (t_0), for each trial (Figure 12). The correlation coefficient r calculated for the final cumulative impulse (t_n) for both methods was .537.

Several factors which could have been operating to reduce these correlations are:

1. In calculating the velocity and impulse of the subject by the segmental method of cinematographical analysis the average "normal" body proportions were assumed. In determining the percentage distance that the segmental centre of gravity is between two reference joint centres Dempster (13) gives the following percentage ranges:

a. Axial skeleton percentage range is $\pm$ 4.4%

b. The Lower Limbs percentage range is $\pm$ 3.8%

c. The Upper Limbs percentage range is $\pm$ 0.6%

2. A camera speed error of $\pm$ 1.5 frames per second occurred in that portion of the film selected for comparative analysis.

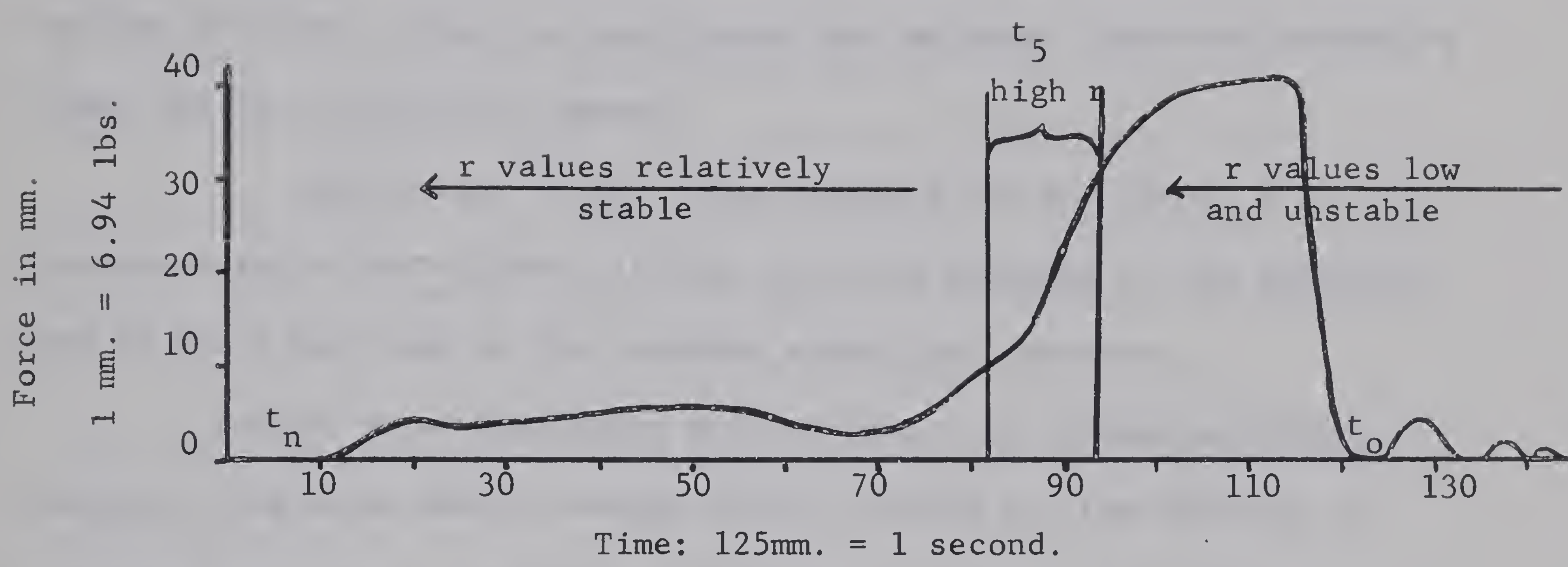


FIGURE 12

SAMPLE FORCE PLATFORM GRAPH, TYPE III START

INDICATING AREA OF CORRELATION VALUES

3. The forces recorded by the force platform are the forces exerted by the individual through his base of support. These may be somewhat different than those determined from a knowledge of the path of the individual's mass centre of gravity.

4. The common reference point selected for comparative analysis may not have been common to both analytical methods, therefore producing lower initial correlation scores.

5. Calibration of the force platform did not enable a determination of the effect, if any, that the movement of the platform bed on the U bars had on the recorded electrical currents.

Further experimentation and refinement of cinematographical analysis, and experimental design should provide for the addition of valuable knowledge to the fields of physical education and athletics.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The purpose of this study was to analyze the frontal and vertical component forces, and the movement time for three selected sprint starts in swimming. The starts selected were the full arm circle (Type I), the partial arm circle (Type II), and the arms back (Type III). A constant, preferred, foot spacing was maintained throughout all testing trials. The relationship between impulses calculated at selected points on the force curve, as measured by the force platform, and by cinematographical analysis, was determined as a means of evaluating the force platform.

The subjects were four experienced male competitive swimmers ranging in age from 17 to 27, inclusive. They were individually trained on sprint starting for a total of six hours over a five week period. After completion of the training period the subjects were weighed and tested, performing three trials for each of the three types of starts used.

A specially designed force platform equipped with U bars and strain gauges attached as a Wheatstone bridge, a circuit control panel and an operational amplifier were used to measure, sum, and amplify the forces before being recorded on a magnetic tape recorder. A 16 mm. spring driven camera was used in conjunction with this platform so

that cinematographical analysis of the starts could be obtained, and the results compared to those obtained on the force platform. Readouts from the force recordings were obtained with a Brush Recorder, model Mark II, at a paper speed of 125 mm/second and a volt/chart line setting of .01 volts/cm. Movement time, velocity, and impulses were obtained from these graphical readouts, while impulses were obtained by cinematographical analysis. Velocity and impulses were calculated on the basis of standard physical formulae.

Cumulative impulses obtained by cinematographical analysis were correlated with cumulative impulses obtained from the force platform graphs, with a compensating planimeter, for comparative times during the start.

II. CONCLUSIONS

Within the limitations of this study, statistical analysis of the data would suggest the following conclusions:

1. There is no significant difference in movement time between the three selected types of starts.
2. There is no significant difference in the velocity of the subject, as he clears the block, between the three starts.
3. Correlation coefficient analysis indicates that starting velocity can not be predicted from a knowledge of the movement time, for any of the three types of starts.
4. On the basis of correlations obtained on impulse values for equivalent time periods by the two techniques, the force platform appears to be a valid instrument of measurement.

5. Cinematographical analysis techniques are useful for evaluating equipment and for determining impulse, and as a result velocity, in adverse testing situations.

6. The force platform provides a fast method of viewing forces exerted on it, and thus of determining the effectiveness of the movement.

III. RECOMMENDATIONS

The following recommendations resulted from problems incurred in this study:

1. In the segmental method of cinematographical analysis the plotting of joint reference points often becomes extremely subjective. Therefore, these locations should be marked on the subject's body in a distinct and contrasting color, prior to the commencement of testing. The problems of perspiration or the water media of starts in swimming will necessitate the use of some indelible substance.

2. The use of a motor driven, constant speed, camera with shutter speeds in excess of 100 frames per second would greatly increase the accuracy of the obtainable data from cinematographical analysis of the physical actions under investigation.

3. In calculating movement time, impulse and velocity from force graphs, research is needed to determine at what point in the graphical readout that the subject leaves the block and the point where the recording pen "tail-off" begins. Greater

knowledge of this point in the force graph would seem necessary in reducing the existing error in comparing impulses and velocity as determined by actual and cinematographical techniques.

4. Further studies are required using force platforms and cinematographical analysis before the true value of either method of research can be accurately assessed.

5. There is a need for additional work with larger samples in order to better evaluate the effectiveness of the three basic styles of sprint starts in swimming.

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APPENDIX

APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Analysis of Variance. The F-ratio was obtained from analysis of variance: one-way classification (20:292)

Subjects	Start 1	Start 11	Start 111	
1	________	________	________	
2	________	________	________	
3	________	________	________	
4	________	________	________	
n_j	________	________	________	N
T_j	________	________	________	T
$\bar{X}$	________	________	________	T^2/N
$\sum^{nj} X_{ij}^2$	________	________	________	$\sum_{j=i}^{K} \sum_{i=1}^{nj} X_{ij}^2$
T_j^2/nj	________	________	________	$\sum_{j=i}^{K} T_j^2/nj$

SUM OF SQUARE

Between . . . . $\sum^{K} T_j^2/_{nj} - \frac{T^2}{N}$

Within . . . . $\sum_{j=1}^{K} \sum_{i=1}^{N} X_{ij}^2 - \sum_{j=1}^{K} \frac{T^2_j}{nj}$

Total . . . . $\sum_{j=1}^{K} \sum_{i=1}^{nj} X_{ij}^2 - \frac{T^2}{N}$

ANALYSIS OF VARIANCE

Between	$\div$ $k - 1 = S_b^2$	
Within	$\div$ $N - k$ S_w^2	
Total	$N-1$	$F = Sb^2/S_w^2$

Correlation Coefficient. The correlation coefficients were computed by use of the Pearson Product-Moment correlation coefficient. The formula used was (20:111):

$$r = \frac{N \sum XY - \sum X \sum Y}{\sqrt{\left[N \sum X^2 - (\sum X)^2\right] \left[N \sum Y^2 - (\sum Y)^2\right]}}$$

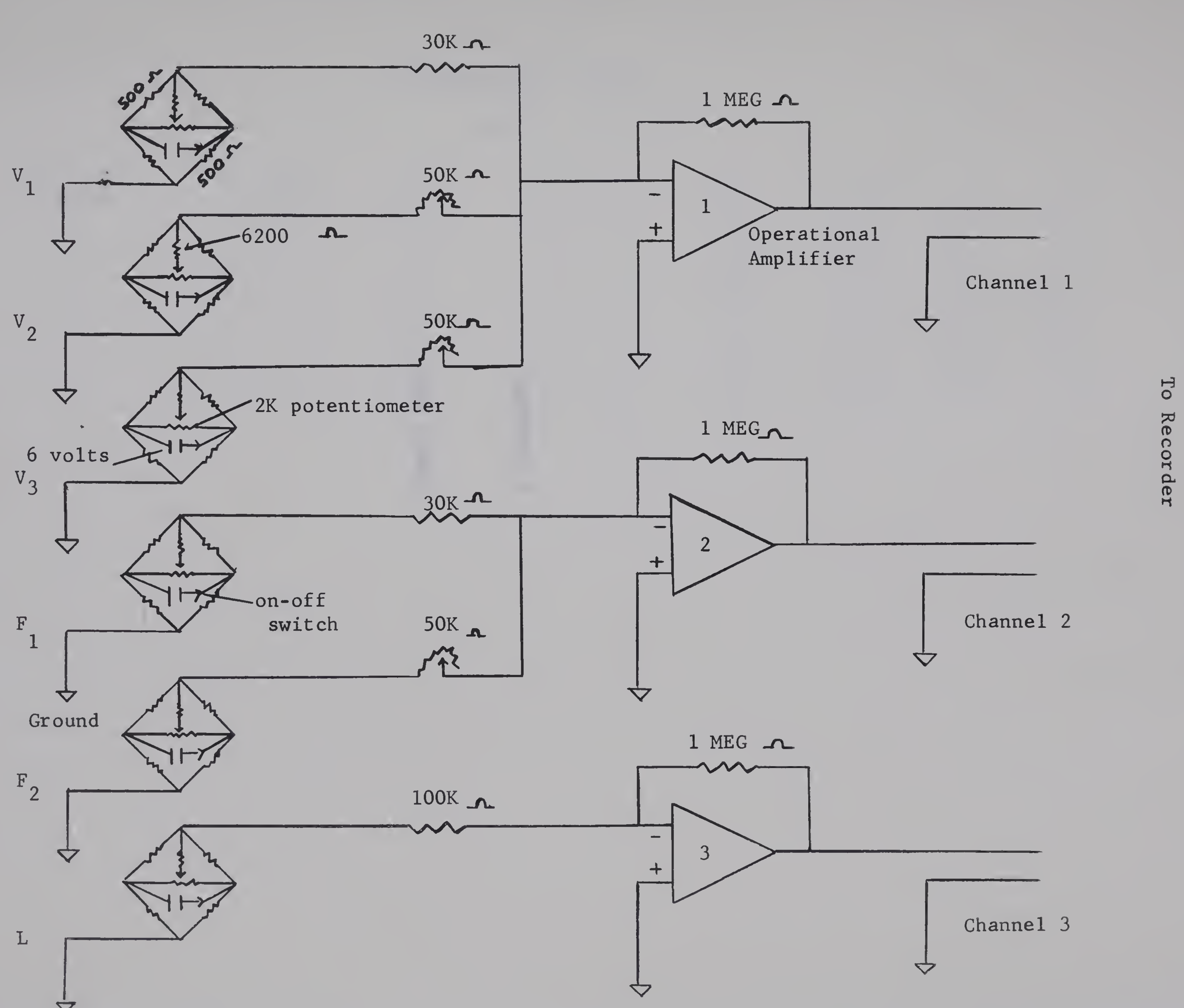
ORDER OF TESTING

Subject	Type	Trial
1	I	1
2	I	1
3	I	1
4	I	1
1	I	2
2	I	2
3	I	2
4	I	2
1	I	3
2	I	3
3	I	3
4	I	3
1	II	1
2	II	1
3	II	1
4	II	1
1	II	2
2	II	2
3	II	2
4	II	2
1	II	3
2	II	3
3	II	3
4	II	3

Subject	Type	Trial
1	III	1
2	III	1
3	III	1
4	III	1
1	III	2
2	III	2
3	III	2
4	III	2
1	III	3
2	III	3
3	III	3
4	III	3

APPENDIX B

CIRCUIT DIAGRAM OF CONTROL PANEL



APPENDIX C

RAW SCORES

SEGMENTAL BODY WEIGHTS

POUNDS

Subject	Head, neck trunk	Arm	Forearm	Hand	Thigh	Leg	Foot
1	84.67	7.75	4.59	1.72	27.84	12.92	4.02
2	100.45	9.21	5.46	2.05	33.08	15.35	4.77
3	91.45	8.37	4.96	1.86	30.07	13.95	4.34
4	94.40	8.64	5.12	1.92	31.04	14.40	4.48

MOVEMENT TIME

SECONDS

	TYPE I			TYPE II			TYPE III		
Subject	1	2	3	1	2	3	1	2	3
1	.832	.804	.830	.868	.848	.840	.880	.880	.832
2	.856	.844	.844	.904	.860	.904	.890	.884	.928
3	.844	.788	.800	.820	.812	.846	.832	.840	.892
4	.888	.804	.900	.872	.788	.856	.912	.984	.888

FRONTAL VELOCITIES - FORCE GRAPHS

FEET PER SECOND

	TYPE I			TYPE II			TYPE III		
Subject	1	2	3	1	2	3	1	2	3
1	16.855	17.661	18.306	17.419	17.177	16.371	17.581	17.339	17.742
2	16.299	16.502	16.299	16.231	16.910	15.823	16.095	15.076	15.740
3	14.332	16.422	16.198	16.348	16.571	16.571	17.019	16.497	16.090
4	15.246	15.246	15.463	15.319	15.535	15.680	17.053	14.596	15.246

VERTICAL VELOCITIES - FORCE GRAPHS

FEET PER SECOND

	TYPE I			TYPE II			TYPE III		
Subject	1	2	3	1	2	3	1	2	3
1	.484	.403	.081	.848	.323	.484	.645	.887	.887
2	.339	-.204	-.136	.815	-.611	.815	1.290	-.339	.068
3	.523	1.120	.896	.970	.821	.224	.597	.523	.821
4	1.084	.145	.289	.795	1.228	..217	.145	.795	.867